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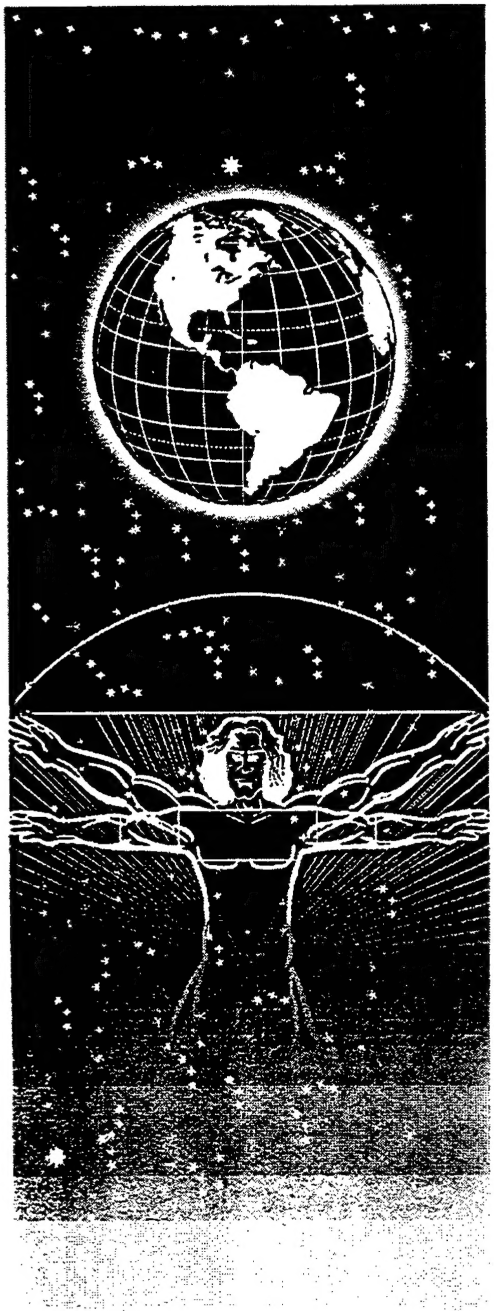

# UNITED STATES AIR FORCE RESEARCH LABORATORY

## DISPLAY COLLIMATION AND THE PERCEIVED SIZE OF FLIGHT SIMULATOR IMAGERY

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Observers estimated differences in the apparent size and distance of simulated objects viewed on collimated and real-image displays. High-resolution target aircraft that remained stationary relative to the observer were superimposed on moving simulator background imagery. The aircraft were slide projections of F-15s viewed either from the side as during formation flight, or from behind and above, as during a gun pass. Both pilots and nonpilots were tested during simulated passive flight. For both the size and distance estimates, differences of 15-30% were found for formation flight at distances of 2,500; 6,000; and 9,000 ft; and differences of 10-20% were found for gun passes at distances of 1,000 and 2,000 ft. No significant differences were found in the data obtained from the pilots and nonpilots under any of the conditions tested. The data generally confirm, for simulator imagery, that both perceived size and perceived distance are significantly reduced when imagery is displayed at viewing distances of less than about 1 m as compared to when it is displayed at or near optical infinity. The implications of magnifying real imagery displayed within about 1 m of the observer, in order to correct for the perceptual size and distance effects reported here, are discussed.

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## PREFACE

The research described in this report was conducted by Detachment 13, Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Training Research Division (AFRL/HEA), under Work Unit 1123-B1-04, Visual Training Research, Work Unit Monitor, Dr Byron J. Pierce. Support was provided by The Raytheon Company under Work Unit 1123-B0-01, Warfighter Training Research Support, Air Force Contract F41624-97-C-5000. The Laboratory Contract Monitor was Mr M. Jay Carroll.

We would like to thank Mr Richard Olson for assembling the collimated and real-image display systems, and Ms Lynette Hewson for help in preparing the manuscript.

# DISPLAY COLLIMATION AND THE PERCEIVED SIZE OF FLIGHT SIMULATOR IMAGERY

## INTRODUCTION

It is well known that the oculomotor state of the eyes (i.e., ocular vergence and accommodation) can affect the perceived size of viewed objects (Gogel, 1962; Heinemann, Tulving, & Nachmias, 1959; Hochberg, 1971). Many flight simulator displays use real imagery that is displayed within about one meter of the eye, and that therefore induces significant vergence and accommodation. Given the perceptual effects mentioned above, and given that an observer's vergence and accommodation levels are greater when viewing real imagery than they are in the real world, it might be expected that the perceived size of displayed objects will not correspond to the physical object size determined by the perspective calculations typically used to generate visual imagery. Roscoe (1984), for instance, describes the systematic errors in size and distance perception that are characteristic of computer-generated imagery.

The Display for Advanced Research and Training (DART) is an operational, real-image display developed at the Warfighter Training Research Division of the Air Force Research Laboratory (Thomas & Geltmacher, 1993; Thomas & Reining, 1990). Different versions of the DART use displays located at either 0.94 or 0.61 m from the observer. The vergence and accommodation levels required to view these displays are well within those known to be associated with the perceptual-size effects referred to above. As a first step in assessing the perceptual effects that may be associated with using real-image displays, Wetzel, Pierce, and Geri (1996) measured the relative perceived size of objects viewed alternately on near (0.61 or 0.94 m) and far (8 m) real-image displays. The stimuli were displayed using rear-projection CRTs similar to those used in the DART. It was found that objects displayed at either of the near distances appeared smaller than objects of the same angular size displayed at the far distance. This result is consistent with the perceived-size effects that have been found for other types of stimuli and other viewing conditions.

The study by Wetzel, *et al.* (1996) was primarily concerned with whether changes in oculomotor state alone could account for the changes in perceived size of objects viewed on CRT displays at distances similar to those used in the DART. Their approach required reduced-cue conditions and relatively simple stimuli, and so the results could not be fully generalized to the more complex visual scenes and objects typically used in flight simulation. In the present study, size estimates were obtained using realistic test stimuli, moving background textures, and distance cues more similar to those available in operational simulators.

## METHOD

### Observers

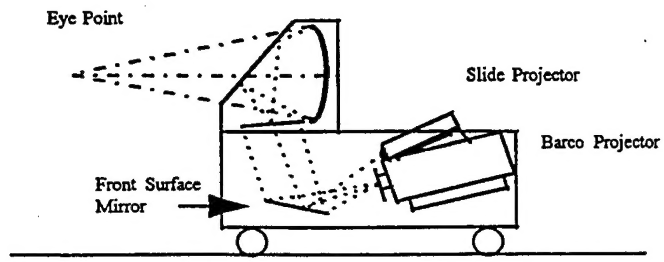
Eight observers (five pilots and three nonpilots) participated in the size and distance estimation experiments. The ages of the observers ranged from 30 to 53 years with a mean of 39 years. Flight experience for the pilots ranged from 1,900 hr to 4,500 hr with a mean of 2,960 hr.

### Apparatus and Stimuli

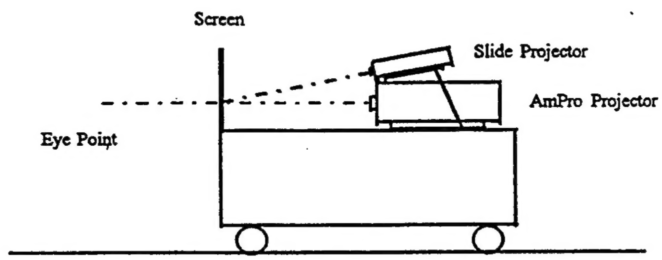
A diagram of the optical system used to display both the real and collimated CRT imagery is shown in Figure 1. The imagery of each channel was rear-projected onto rigid screens (Stewart Lumiglass 130). One image was viewed directly at a distance of 1.12 m (44 in) and thus served as the real image. The other image was reflected in a large spherical mirror and was effectively collimated. The two images were superimposed using a large glass beamsplitter. The sources of the real and collimated images were an Ampro Model 3300 CRT projector and a Barco Model 801 CRT projector, respectively.

The background images used in the formation flight (FF) and gun pass (GP) conditions are shown in Figures 2a and 2b, respectively. High-resolution targets on 35 mm slides were superimposed on the background imagery in each channel. In one condition, the targets were chosen to represent F-15s flying in FF with the observer's aircraft at distances of 2,500; 6,000; or 9,000 ft. In each case, the observer's aircraft and the target aircraft were simulated at altitudes of 4,000 and 4,250 ft, respectively. Target aircraft were displayed above the horizon for both conditions and all distances tested. In addition, for the 6,000 ft viewing distance, size and distance estimates were obtained using target aircraft located below the horizon. In this condition, the observer and target aircraft were at altitudes of 4,000 and 3,750 ft, respectively. In the final condition, the observers' viewed the target aircraft in a GP (45° left bank) at distances of either 1,000 or 2,000 ft, with both aircraft at an altitude of about 4,000 ft.

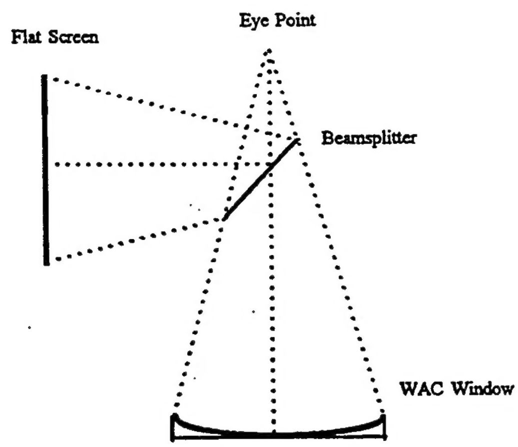
Examples of the target stimuli for the FF (looking up and looking down) and GP conditions are shown in Figure 3. The F-15 models used to produce the target stimuli were obtained from Viewpoint Data Labs. The appropriate perspective for the models was generated using SoftImage-3D (Microsoft), and the model was scaled as required using Adobe Photoshop. The background imagery was obtained from a typical flight simulator database. Observers' head movements were minimized with a chin rest, and a two-button response box was used for data collection.




a) Collimated-Image Projection System (WAC Window)

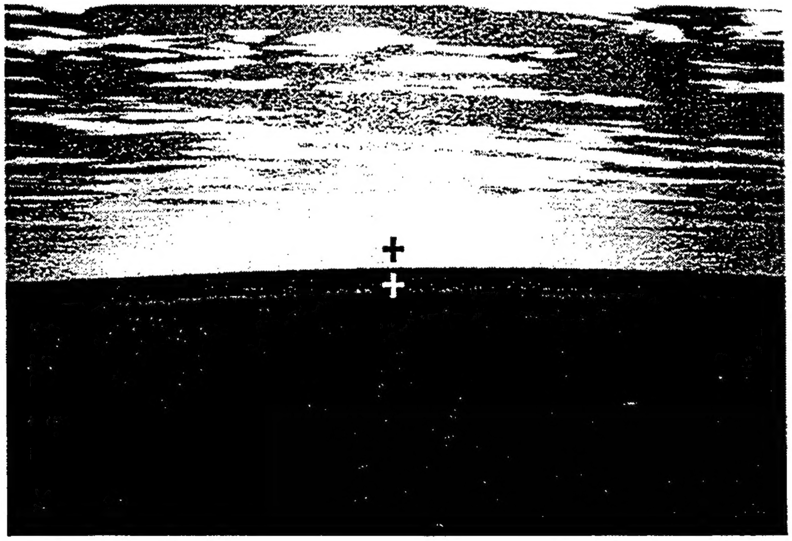



b) Real-Image Projection System

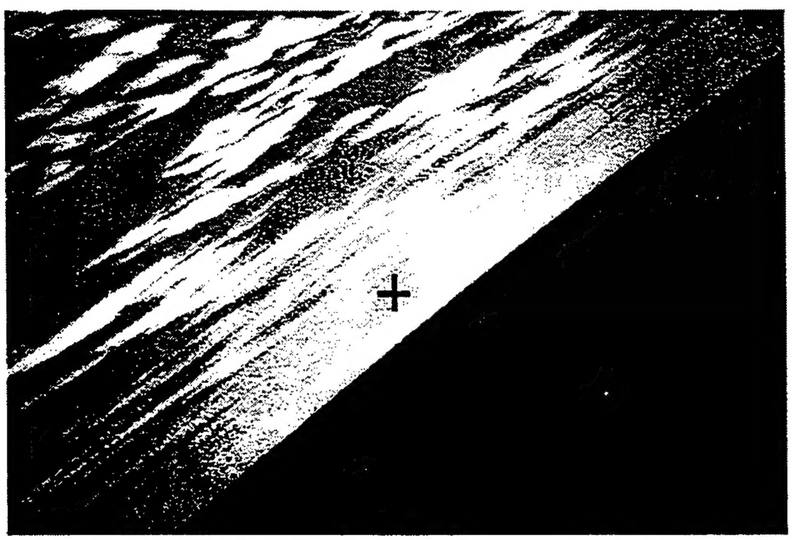



c) Top View of Combined Projection System

*Figure 1. Diagrams of the Collimated-Image and Real-Image Display Systems.*

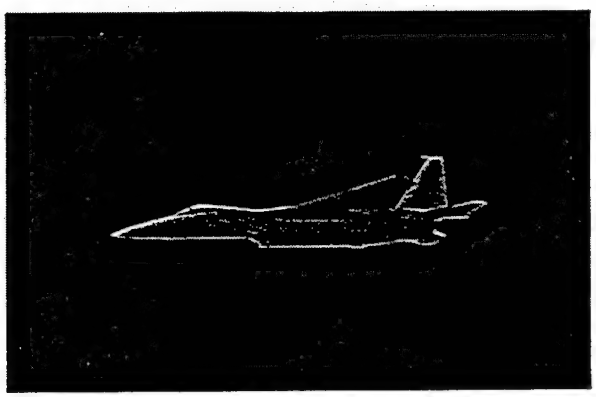


a) Formation Flight

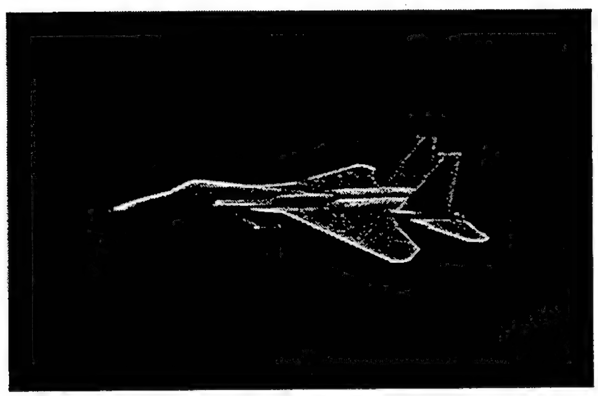


b) Gun Pass

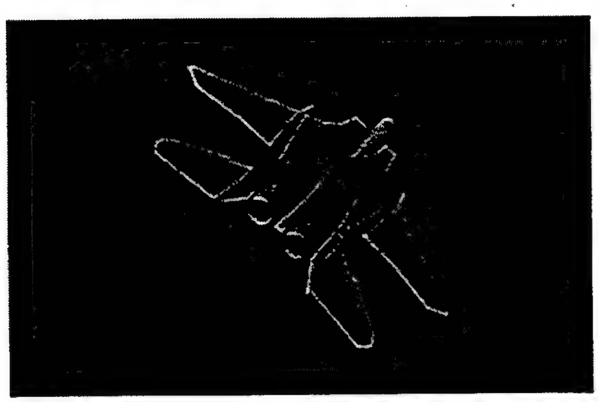
*Figure 2. Background Images Used in the FF (a) and GP (b) Conditions.*



a) Formation Flight-looking up



b) Formation Flight-looking down



c) Gun Pass

*Figure 3. Target Stimuli Used for the Three Flight Conditions.*

**Procedure**

Observers were first allowed to adapt for 4-5 min to the general level of illumination provided by the displays (approximately 15 fL). Both the size-estimation and distance-estimation trials began with a 5 s presentation of the collimated target and background image. That image was extinguished and the uncollimated (real image) target and background were presented for 5 s. Using a response switch, the observer then indicated whether the real test target appeared larger or smaller (size), or farther or nearer (distance), than the collimated test target. The size of the variable image was determined using a staircase with steps of approximately 2.3% of the standard for distances up to and including 2,500 ft. The step sizes for the remaining distances (6,000 ft and 9,000 ft) were approximately 11.8% of the standard. A trial ended when the staircase appeared to the experimenter to have stabilized after at least ten response reversals. Six blocks of trials (corresponding to four FF distances and two GP distances) were run in each experimental session which lasted about 40 min. The order in which the six distances were tested was randomized for each session. The size-estimation and distance-estimation data were collected on separate days for each observer.

After data collection was completed, observers were questioned as to their age, flight experience, judged fidelity of simulated imagery, and the criteria and cues they used to judge size and distance.

**Data Analysis**

For both the size and distance estimation conditions, the relevant data were the points where the response staircase reversed direction. A percentage size difference (measured in visual angle) was obtained by subtracting the mean of all response reversals from each corresponding standard size or distance (i.e., the size or distance of the collimated-image test target) and multiplying the result by 100. These percentages were used as the dependent variables in a split-plot factorial (Kirk, 1968) Analysis of Variance (ANOVA). Because of the limited number of observers, separate ANOVAs were performed for the size and distance data. The ANOVAs were run using SPSS (Release 6.1.3). The between-subjects variable in the ANOVAs was Flight Experience (pilots vs. nonpilots) and the within-subjects variable was Viewing Distance (1,000; 2,000; 2,500; 6,000 and 9,000 ft). Five *a priori* contrasts were tested. Contrast 1 compared the FF and GP conditions. Contrast 2 compared the 1,000 and 2,000 ft viewing conditions (GP). Contrast 3 compared the looking-up and looking-down conditions for the 6,000 ft viewing distance (FF). Contrast 4 compared the 2,500 and 9,000 ft viewing distances (FF). Contrast 5 compared the mean of the 2,500 and 9,000 ft viewing conditions with the mean of the looking-up and looking-down conditions at the 6,000 ft viewing distance (all FF). Due to the increased Type I familywise error rate associated with the use of planned comparisons, all alpha levels for

the planned comparisons were adjusted ($\alpha = 0.04$) using a modified Bonferroni test (Keppel, 1991). Five planned comparisons were examined for the Distance variable under both dependent variables of Perceived Size and Perceived Distance.

In addition to the two standard ANOVAs described above, two additional ANOVAs were performed, in which all of the 8-12 staircase reversals for each condition were used (rather than just their mean as in the original two ANOVAs). In one ANOVA, a Full Rank model (Timm & Carlson, 1975) provided a test for difference from zero for the size and distance estimates for each condition and each observer. In the other ANOVA, Observers was added as a random factor, and the data were the means obtained over all target sizes and flight conditions. For both the size and distance data, the means for the pilots and nonpilots were tested separately using pairwise comparisons among the individuals within each group.

## RESULTS

Size and distance estimates obtained from the five pilots and three nonpilots are shown in Figures 4 and 5, respectively. The figures show the percentage difference in the perceived size (triangles) or distance (circles) of the real image relative to the collimated image that served as the standard. The filled and open symbols correspond to data from the FF and GP conditions, respectively. A positive difference in perceived size indicates that the real image was perceived to be smaller than the corresponding collimated image. A positive difference in perceived distance indicates that the real image was perceived to be farther away than the corresponding collimated image. As can be seen in Figure 4, for the FF condition, differences in both perceived size and perceived distance were generally consistent for four of the five pilots (all except observer JC) at each standard size tested. For the GP condition, however, there were notable differences between the size and distance data for four of the five pilots at least one standard size. Averaged data are shown separately in Figure 6 for all five pilots and all three nonpilots for both the FF and GP conditions.

The ANOVA performed on the perceived size data showed a significant effect for Contrast 1 only (FF vs. GP; $F_{1,30} = 7.68$, $p < 0.01$). Likewise, only Contrast 1 was significant for the ANOVA performed on the perceived distance data ($F_{1,30} = 6.36$, $p < 0.02$). The main effects for Experience, all interactions, and all other contrasts were not significant ($p > 0.05$) [see Appendix A, Tables 1 and 2].

The Full Rank model ANOVA showed that for the perceived size data, 47 of the 48 measured differences between the near and far viewing distances (i.e., the data points of Figures 4 and 5) were significantly different from zero ($p < 0.5/48 \cong 0.001$). The only nonsignificant difference was found for observer PF under flight condition GP at the 1,000 ft altitude. For the

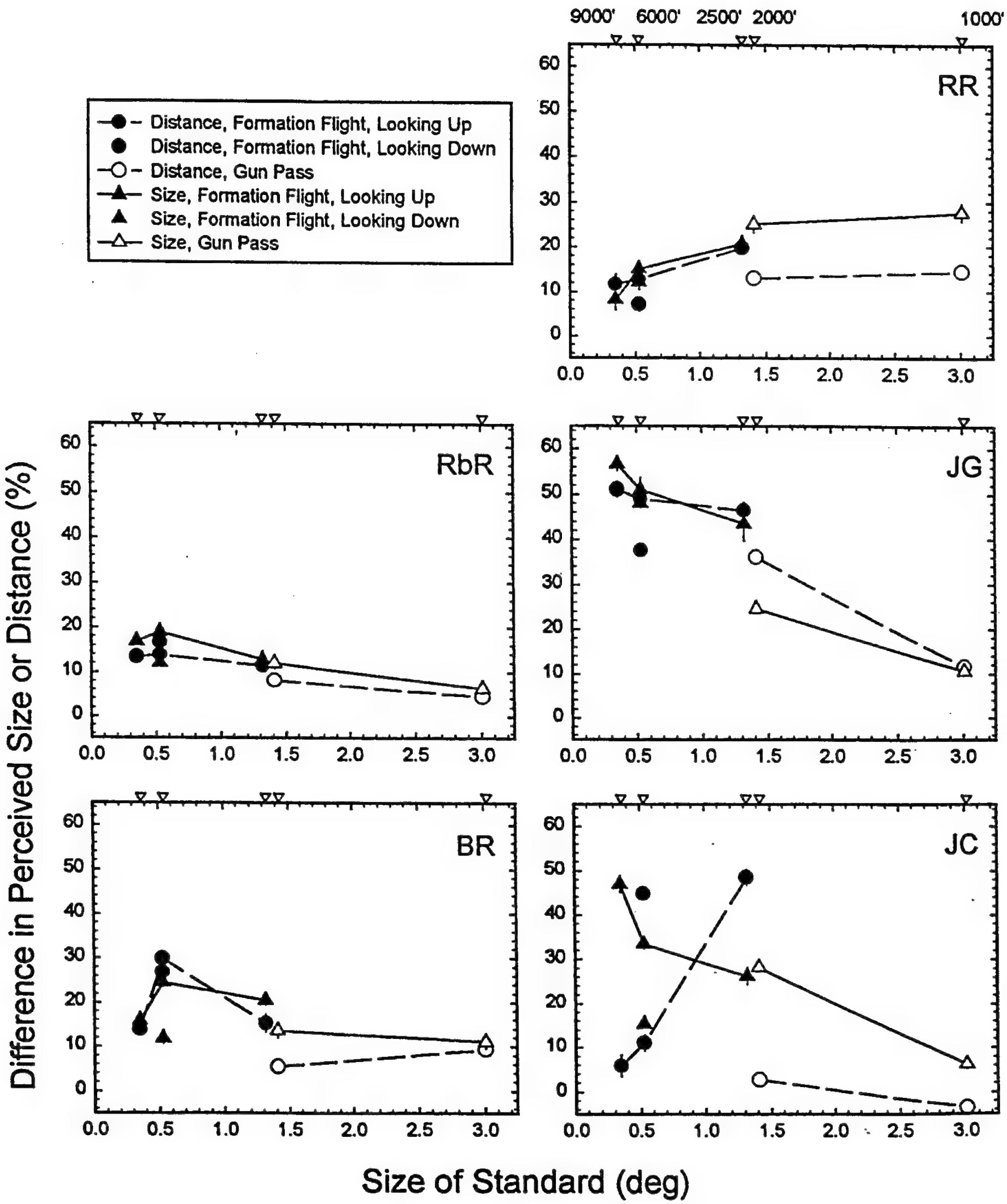



*Figure 4. Size and Distance Estimates Obtained From the Five Pilots.*

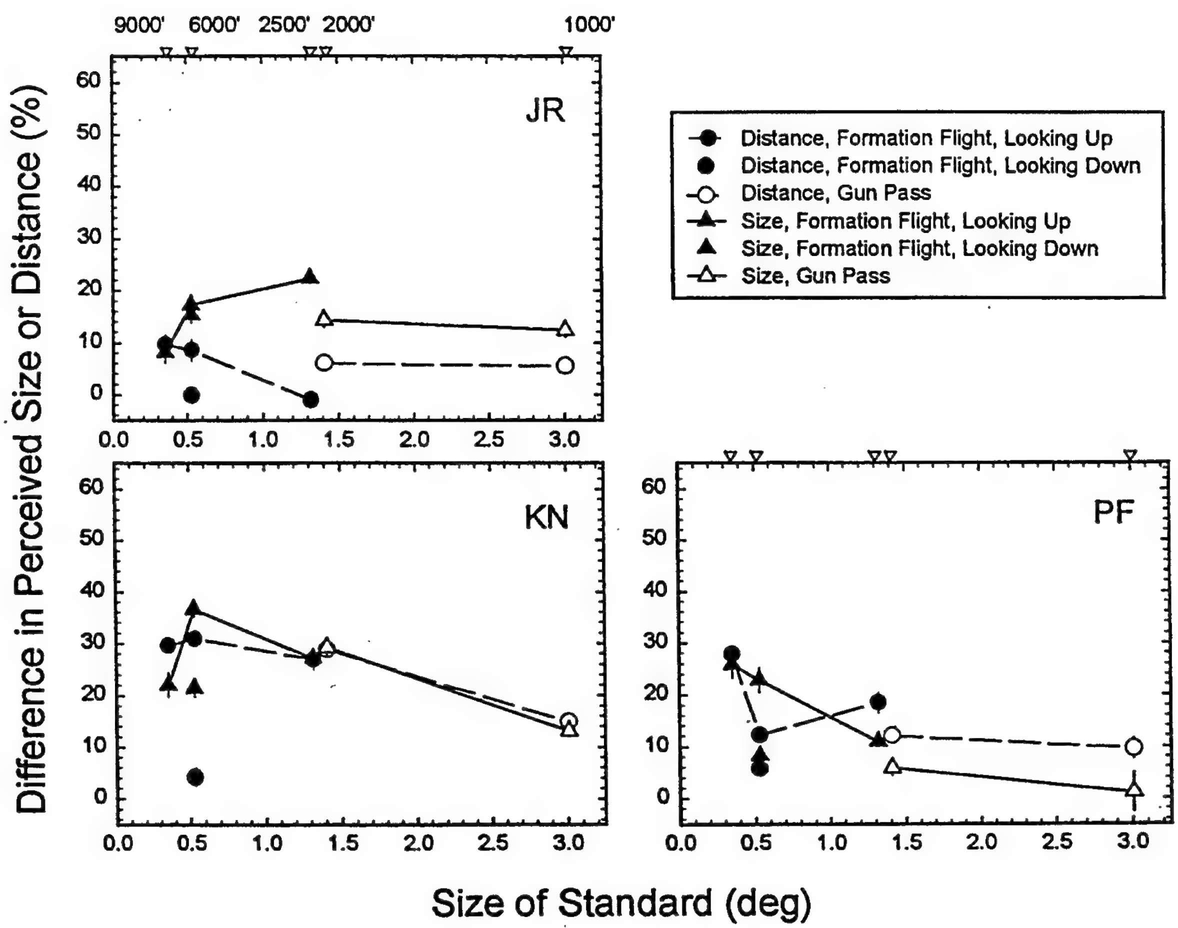



*Figure 5. Size and Distance Estimates Obtained From the Three Nonpilots.*

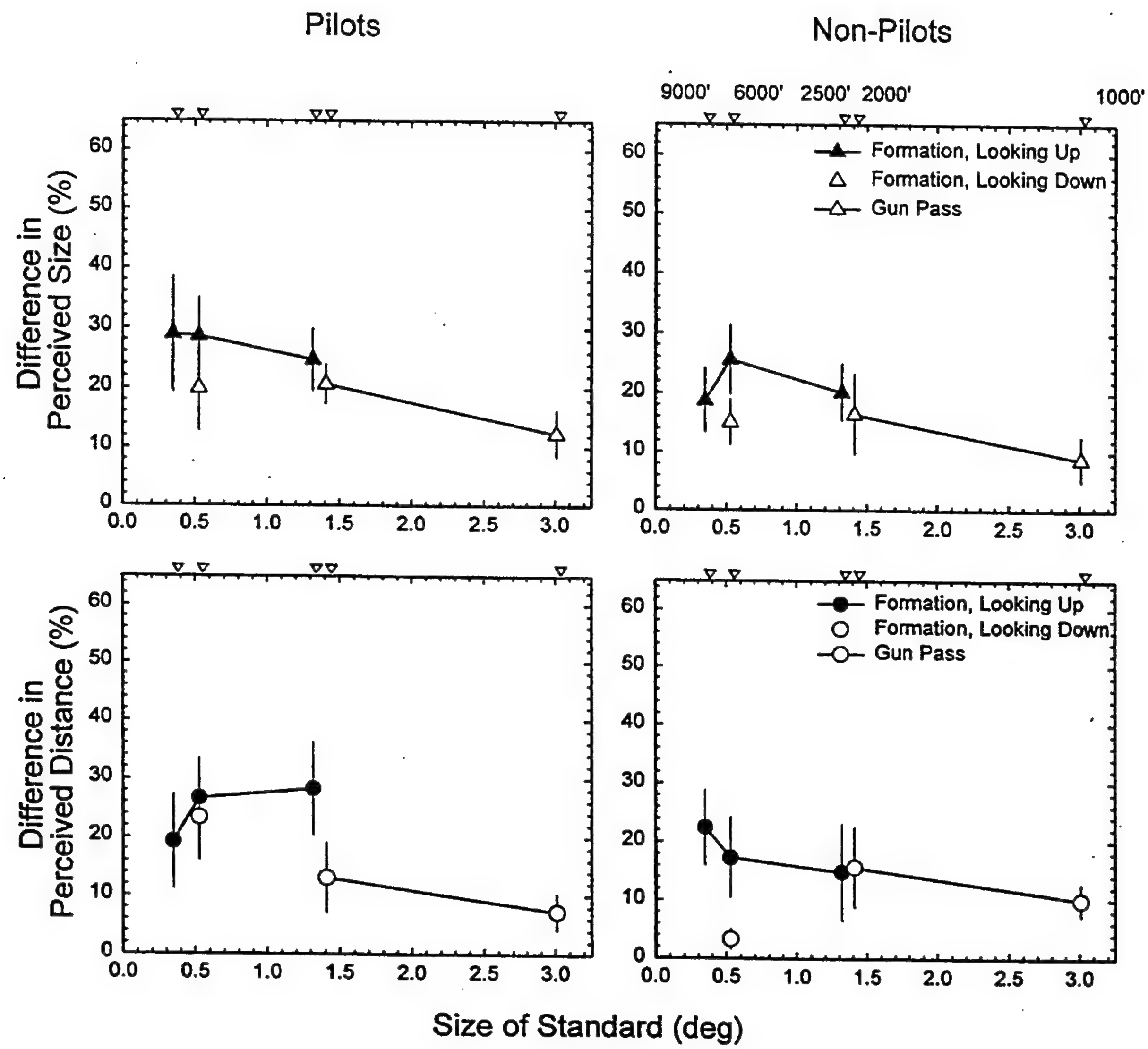



*Figure 6. Size and Distance Data Averaged for the Five Pilots and Three Nonpilots.*

perceived distance data, 42 of the 48 differences were significant. The six nonsignificant differences for the distance data corresponded to the following conditions: (KN, FF, 6,000 ft looking down (ld); PF, FF, 6,000 ft, ld; JC, GP, 1,000 ft; JC, GP, 2,000 ft; JR, FF, 2,500 ft; and JR, FF, 6,000 ft, ld). Summary tables for the Full Rank analysis can be found in Appendix A, Tables 3 and 4.

The data of Figure 4 also suggest that there are considerable individual differences among the size and distance data for the five pilots tested. For the formation-flight condition (filled symbols, corresponding to smaller image sizes), the magnitude of the size and distance differences varied from about 15% (observers RR and RbR) to about 50% (observer JG). For the gun-pass condition (open symbols), differences in perceived size and distance varied from about 10% (observers RbR and BR) to about 25% (observer JG). The data of Figure 5 show somewhat less interobserver variability for the three nonpilots tested. Pairwise comparisons were performed separately among the means of the 5 pilots and the means of the 3 nonpilots, where the means were obtained by averaging the data of Figures 4 and 5 over the six data points corresponding to the data for each observer. Separate analyses were conducted for the size and distance data. For the size data, of the 13 (10 for the pilots and 3 for the nonpilots) pairwise comparisons, all but one (RR vs. BR) were significant ($p < 0.05/13 \cong 0.0038$). For the distance data, all but two (RR vs. RbR and BR vs. JC) of the 13 comparisons were significant. A summary table for the ANOVA used to test the above described contrasts can be found in Appendix A, Tables 5 and 6.

## DISCUSSION

### Simple Model of the Size/Distance Effect

Oculomotor state, and specifically ocular vergence and accommodation, is known to be a cue to object distance (Gogel, 1962; Heinemann, Tulving, & Nachmias; 1959; Hochberg, 1971; Leibowitz, Shiina, & Hennessy, 1972; McCready, 1965; Sedgwick, 1986). As oculomotor state would be expected to be different when collimated and real displays are viewed (Bell & Ciuffreda, 1985), it has particular relevance for the generation and use of simulator imagery. Shown in Figure 7 is a representation of how inconsistent visual cues might result in differences in the perceived size or distance of an object simulated to be at optical infinity but displayed as a real image. We assume, somewhat simplistically, that object size or distance is determined by the observer's "perceptual system" based on its analysis of the independent input from what we are calling the "vergence system" and the "visual system." We further assume that the vergence system assesses the oculomotor state of the eyes while the visual system assesses the size of the retinal image. When viewing real-life objects located at effective optical infinity (beyond about 10 m), ocular vergence is at some relatively low value between about 0° and 0.3°,

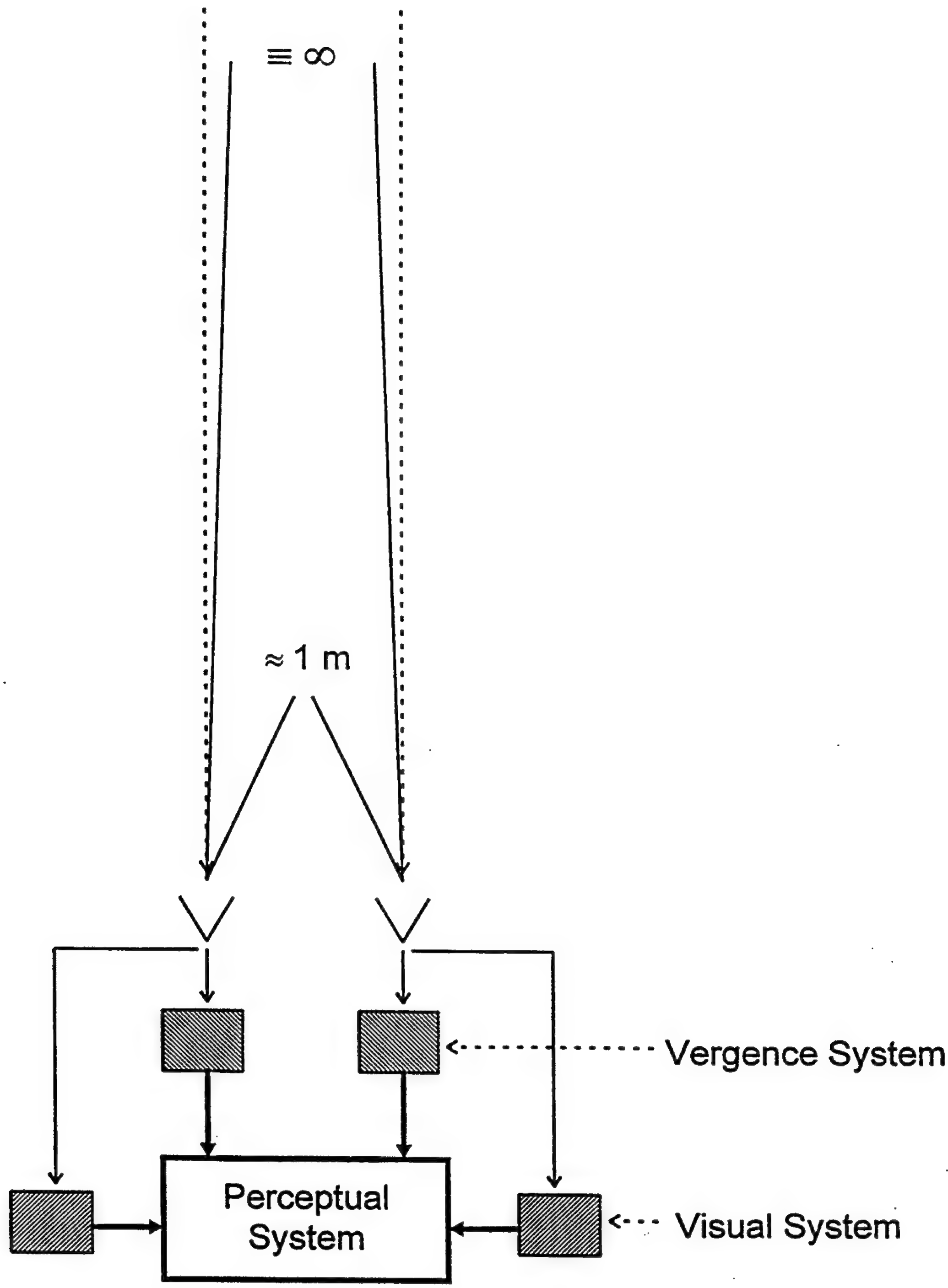



*Figure 7. A Possible Mechanism Underlying the Size-Distance Data.*

depending on the observer. When that same object is viewed on a real-image display, ocular vergence increases to about 2°. On the basis of this vergence change, the vergence system signals to the perceptual system that the object is closer to the observer. However, since the retinal image size associated with the displayed real image is the same as it would be if the object were viewed in the real world at optical infinity, the visual system signals to the perceptual system that the object is at the relatively large simulated distance. Thus, our working hypothesis is that in order to reconcile a constant retinal image size (indicating no difference in distance) with a higher vergence level (indicating that the object is closer), the object must be perceived as smaller than its simulated retinal image size would otherwise dictate.

**Size/Distance Data and Visual Cues**

The data of Figures 4-6 show that when a collimated standard stimulus is compared with a variable stimulus located 1.1 m from the observer, the two stimuli appear different in both size and distance even though they subtend the same visual angle. Given that our aircraft stimuli were familiar objects (especially for the pilots tested), we assume that the differences in both perceived size and distance are due to visual cues that indicate that the stimuli are at different distances. For both the size and distance data, differences between the collimated and real imagery of 15-30% were found for formation flight (at distances of 2,500; 6,000; and 9,000 ft), and differences of 10-20% were found for gun passes (at distances of 1,000 and 2,000 ft). The differences in perceived size and distance under the FF and GP conditions were statistically significant suggesting either that there are significant differences in the cues available under these two flight conditions or that the absolute size of the judged aircraft is a relevant variable. It should be noted in this context that the GP aircraft were viewed from above and hence presented larger (in area) targets than the FF aircraft that were viewed from the side. Thus, more texture cues were visible on the GP aircraft, and several pilots claimed to use texture cues to judge distance (and hence size). On the other hand, more background texture cues were available in the FF condition, but only one pilot claimed to use terrain texture to judge distance, whereas three pilots explicitly stated that they did not believe that it was a reliable cue to object distance in the simulator.

Roscoe (1984) has described a number of viewing situations that result in what he characterizes as systematic errors in size and distance judgments. Although he notes that there are considerable individual differences, he suggests that a magnification of about 25% is sufficient to assure that objects appear at the appropriate distance. The data of Figures 4-6 appear to be consistent with Roscoe's estimates.

Only seven of the data points plotted in Figures 4 and 5 represent statistically non-significant differences in perceived size and distance. Of these, three correspond to the 6,000 ft looking down condition for the nonpilots. This condition might be expected to provide the most

salient cues to a pilot since it involves viewing the aircraft stimulus against a moving textured background. Although it is not appropriate to draw a statistical inference from this negative result, it is consistent with the assumptions that typical flight simulator imagery provides size and distance cues and that pilots may be more sensitive than nonpilots to those cues.

There were no significant differences between pilots and nonpilots in the perception of the size or distance of aircraft ranging in size from about 0.4 to 3.0 deg. of visual angle. This suggests that the cues to size and distance provided by typical flight simulator imagery are salient enough to be used by anyone viewing that imagery. Among the cues that the pilots reported to have used to judge size and distance were the size of the target aircraft as they remembered them, and the visibility and color of the surface texture on the target aircraft. Ocular vergence is also an important cue to object distance and size, but it is not one of which observers are consciously aware. Wetzel *et al.* (1996) found that ocular vergence can mediate size differences of about 15-25% under reduced cue conditions wherein that vergence is the only identifiable cue to stimulus distance. Those reduced-cue data have been reproduced in the upper left panel of Figure 8 where they are compared to data summarized from the present study. Although the data are qualitatively similar, there is a slightly larger effect, especially at smaller sizes, in the present study as compared to the reduced-cue laboratory study. This might be due to the additional cues to object size and distance which are available in the simulator (see above), but also suggests that those more obvious cues do not add significantly to the size and distance cues provided by ocular vergence.

Finally, one difference between the data of Wetzel *et al.* (1996) and those of the present study should be noted. Wetzel *et al.* found a significant difference in perceived size for their 2° stimulus as compared with either their 1° or 3° stimuli. The size effect reported here, between the FF and GP flight conditions, corresponds to stimuli subtending 1° (or less) and 3°. We cannot, at present, explain this quantitative difference in the two data sets.

**Possible Implications for Flight Simulation**

In real-image simulators, such as the DART, pilots view stimuli located less than 1 m away. Therefore, the fact that estimates of target size obtained from real image and collimated image displays do not correspond (see Figures 4-6) may be attributable to the perceptual effects associated with changes in viewing distance. The present data confirm the visual perception literature in that objects presented on our real image display appeared smaller than those presented on our collimated displays. These data suggest, therefore, that a more realistic simulation may be produced by magnifying the displayed imagery by 10-25%. The

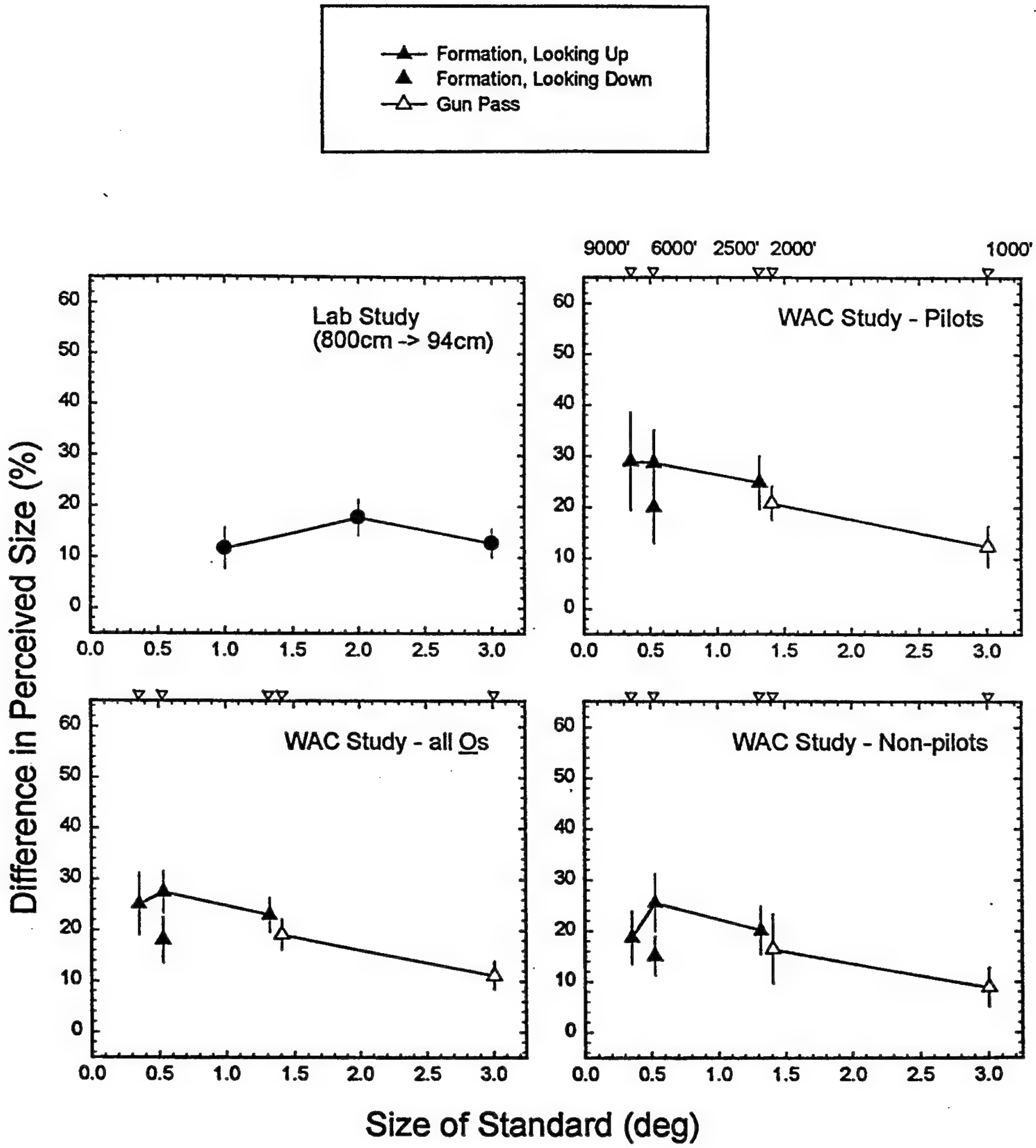



*Figure 8. A Comparison of the Present Data with Previous Laboratory Data.*

simplest such approach would be to magnify a limited number of objects of interest, such as companion aircraft in formation flight, enemy aircraft in air-to-air engagements, or ground objects associated with tasks such as low-level flight or ordnance delivery. The problem with this approach is that size relationships among the magnified objects and the terrain and cultural features which are not magnified may be distorted. In the latter group may be roads, rivers, or foliage whose size relative to the magnified objects may be relevant for the proper performance of various flight tasks.

A more complete approach to magnifying simulator imagery would be to magnify all objects and features in the relevant database. This could in principle be done with no additional computation since any standard database need only be replaced by a magnified version of itself. One problem with this approach, however, is that no full-field (i.e., 360°) database can be magnified in its entirety since, by definition, such magnification would result in objects subtending more than the entire 360° field-of-view. This problem could be dealt with by only magnifying the displayed image locally about the point of gaze. In this case, any visual field distortions associated with the local magnification can be placed far enough in the visual periphery to be invisible to the pilot. Of course the local magnification approach would require more computational resources because the pilot's gaze position would have to be measured and the appropriate portion of the displayed image magnified in real time.

As described above, the present data, obtained using complex simulator imagery, generally confirm the results obtained using simpler stimuli presented in reduced-cue, laboratory conditions. The logical next stage of this research would be to identify tasks that are typically performed in real-image simulators and which may be affected by the perceptual size and distance effects described here. Despite great advances in image generators and visual displays, current simulators still do not provide the resolution required for many tasks, especially those involving air-to-air combat or low-level flight. In view of these limitations, the size and distance effects reported here may be of little practical importance. However, new display systems are currently being developed, which include both high-resolution insets provided by superimposed CRT imagery, and full-field, high-resolution imagery provided by laser projectors. When these higher resolution systems become available, perceptual effects, including those described here, may become the limiting factor in providing realistic and accurate flight simulator imagery.

## CONCLUSIONS

Perceived size and perceived distance are significantly reduced when imagery is displayed at viewing distances of about 1 m as compared to when it is displayed at or near optical infinity. The present results, obtained using high-resolution test targets and typical flight

simulator imagery, are in general agreement with those previously obtained under reduced-cue conditions wherein oculomotor state was the only identifiable cue to target distance. The similarity of the present data and the reduced-cue data suggests that oculomotor cues are the most practically important for judging target size and distance in real-image displays. Finally, the present results indicate that real-image displays must be magnified by about 20% in order for them to appear to be the same size as collimated-image displays, although significant individual differences were found in the data. It remains to be determined which, if any, tasks typically performed using real-image displays will be significantly influenced by the perceptual effects described here.

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**APPENDIX A**

Data Summary Tables

*Table 1 - Summary Size and Distance Perception Data for the Five Pilots*

| | Pilots | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Size | | | | | | Distance | | | | | |
| | Gun Pass | | Formation Looking-up | | | -down | Gun Pass | | Formation Looking-up | | | -down |
| | 2000' | 1000' | 9000' | 6000' | 2500' | 6000' | 2000' | 1000' | 9000' | 6000' | 2500' | 6000' |
| BR | | | | | | | | | | | | |
| *mean* | 13.64 | 11.09 | 15.89 | 24.53 | 20.51 | 11.82 | 5.48 | 9.30 | 13.88 | 29.91 | 15.30 | 26.89 |
| *sem* | 1.719 | 1.533 | 0.687 | 1.088 | 1.165 | 1.241 | 0.723 | 1.032 | 1.432 | 1.071 | 2.131 | 1.26 |
| JC | 28.26 | 6.27 | 46.90 | 33.53 | 26.29 | 15.38 | 2.74 | -3.45 | 5.90 | 11.08 | 48.48 | 44.86 |
| | 0.948 | 1.058 | 1.876 | 1.320 | 1.891 | 0.926 | 0.831 | 0.912 | 2.341 | 1.862 | 1.841 | 1.006 |
| JG | 24.60 | 10.61 | 56.67 | 51.05 | 43.56 | 48.11 | 36.09 | 11.63 | 51.07 | 49.06 | 46.45 | 37.60 |
| | 0.742 | 0.943 | 1.536 | 2.556 | 3.955 | 1.102 | 1.037 | 0.862 | 1.727 | 1.784 | 1.794 | 1.304 |
| RbR | 12.01 | 6.35 | 16.92 | 19.03 | 12.83 | 12.05 | 8.16 | 4.51 | 13.47 | 13.93 | 11.48 | 16.77 |
| | 1.344 | 0.923 | 0.820 | 0.802 | 1.13 | 0.794 | 0.886 | 0.830 | 1.012 | 1.224 | 1.220 | 1.95 |
| RR | 25.03 | 27.70 | 8.29 | 15.09 | 20.59 | 12.19 | 12.98 | 14.48 | 11.71 | 12.83 | 19.75 | 7.17 |
| | 1.938 | 2.002 | 2.425 | 1.859 | 0.652 | 0.920 | 0.984 | 1.245 | 2.147 | 2.158 | 1.261 | 1.530 |
| *mean* | 20.70 | 12.40 | 28.93 | 28.64 | 24.75 | 19.91 | 13.09 | 7.29 | 19.20 | 25.99 | 28.29 | 26.65 |
| *sem* | 3.289 | 3.957 | 9.572 | 6.399 | 5.165 | 7.080 | 5.993 | 3.143 | 8.092 | 7.811 | 7.942 | 6.814 |
| *mean* | 16.55 | | 27.44 | | | 19.91 | 10.19 | | 24.39 | | | 26.65 |
| *sem* | 2.792 | | 3.927 | | | 7.080 | 3.333 | | 4.360 | | | 6.989 |
| *mean* | 22.55 | | | | | | 19.88 | | | | | |
| *sem* | 2.559 | | | | | | 2.905 | | | | | |

*Table 2 - Summary Size and Distance Perception Data for the Three NonPilots*

| | Non-Pilots | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Size | | | | | | Distance | | | | | |
| | Gun Pass | | Formation Looking-up | | | -down | Gun Pass | | Formation Looking-up | | | -down |
| | 2000' | 1000' | 9000' | 6000' | 2500' | 6000' | 2000' | 1000' | 9000' | 6000' | 2500' | 6000' |
| JR | | | | | | | | | | | | |
| *mean* | 14.33 | 12.39 | 8.19 | 17.30 | 22.42 | 15.44 | 6.03 | 5.51 | 9.67 | 8.63 | -1.01 | -0.11 |
| *sem* | 1.445 | 1.371 | 2.101 | 1.223 | 0.996 | 1.625 | 1.216 | 1.262 | 2.157 | 2.089 | 1.360 | 1.554 |
| KN | 29.26 | 13.17 | 22.08 | 36.60 | 27.20 | 21.51 | 28.87 | 14.92 | 29.67 | 30.94 | 27.02 | 3.48 |
| | 1.645 | 1.097 | 2.249 | 1.353 | 1.531 | 1.691 | 1.236 | 1.195 | 1.275 | 1.582 | 2.038 | 1.716 |
| PF | 5.88 | 1.18 | 25.93 | 22.88 | 10.98 | 8.27 | 12.11 | 9.60 | 27.90 | 12.32 | 18.54 | 5.85 |
| | 1.459 | 3.730 | 2.595 | 2.322 | 0.949 | 1.392 | 1.237 | 1.900 | 1.659 | 1.673 | 2.119 | 1.552 |
| *mean* | 16.49 | 8.91 | 18.73 | 25.59 | 20.20 | 15.07 | 15.67 | 10.01 | 22.41 | 17.29 | 14.85 | 3.07 |
| *sem* | 6.835 | 3.873 | 5.387 | 5.734 | 4.812 | 3.826 | 6.829 | 2.724 | 6.392 | 6.904 | 8.299 | 1.732 |
| *mean* | 12.70 | | 21.50 | | | 15.07 | 12.84 | | 18.18 | | | 3.07 |
| *sem* | 3.900 | | 2.859 | | | 3.826 | 3.523 | | 3.78 | | | 1.732 |
| *mean* | 17.50 | | | | | | 13.88 | | | | | |
| *sem* | 2.164 | | | | | | 2.523 | | | | | |

## APPENDIX B

ANOVA Summary Tables

*Table 1. Standard ANOVA – Size Data*

| | SS | df | MS | F | p |
|---|---|---|---|---|---|
| Experience | 287.94 | 1 | 287.94 | < 1 | |
| Subjects w/in Experience | 3119.36 | 6 | 519.89 | | |
| Flight Type | | | | | |
| Contrast 1 | 656.41 | 1 | 656.41 | 7.68 | < 0.01 |
| Contrast 2 | 236.43 | 1 | 236.43 | 2.77 | 0.12 |
| Contrast 3 | 347.62 | 1 | 347.62 | 4.07 | 0.053 |
| Contrast 4 | 6.89 | 1 | 6.89 | < 1 | |
| Contrast 5 | 5.42 | 1 | 5.42 | < 1 | |
| Group x Flight Type | | | | | |
| Group x Contrast 1 | 8.16 | 1 | 8.16 | < 1 | |
| Group x Contrast 2 | 0.50 | 1 | 0.50 | < 1 | |
| Group x Contrast 3 | 2.98 | 1 | 2.98 | < 1 | |
| Group x Contrast 4 | 29.87 | 1 | 29.87 | < 1 | |
| Group x Contrast 5 | 22.11 | 1 | 22.11 | < 1 | |
| Flight x Subjects | | | | | |
| Within group | 2566.68 | 30 | 85.56 | | |

Contrasts Tested:

Contrast 1 - FF vs. GP
Contrast 2 - GP 1000' vs. GP 2000'
Contrast 3 - 6000' Looking Up vs. 6000' Looking Down
Contrast 4 - 2500' vs. 9000'
Contrast 5 - 2500' and 9000' vs. 6000' Looking up and Down

$Eta^2$ (Contrast 1) = 6.68 / (6.68 + 16) = 0.295
Flight Type accounts for 29.5% of the total variance.

*Table 2. Standard ANOVA – Distance Data*

| | SS | df | MS | F | p |
|---|---|---|---|---|---|
| Experience | 373.87 | 1 | 373.87 | | |
| Subjects w/in Experience | 3831.12 | 6 | 638.52 | | |
| Flight Type | | | | | |
| Contrast 1 | 620.62 | 1 | 620.62 | 6.36 | < 0.05 |
| Contrast 2 | 123.04 | 1 | 123.04 | 1.26 | 0.27 |
| Contrast 3 | 111.94 | 1 | 111.94 | 1.15 | 0.29 |
| Contrast 4 | 2.17 | 1 | 2.17 | < 1 | |
| Contrast 5 | 96.81 | 1 | 96.81 | < 1 | |
| Group x Flight Type | | | | | |
| Group x Contrast 1 | 389.11 | 1 | 389.11 | 4.08 | 0.052 |
| Group x Contrast 2 | 0.02 | 1 | 0.02 | < 1 | |
| Group x Contrast 3 | 287.84 | 1 | 287.84 | 2.59 | 0.096 |
| Group x Contrast 4 | 259.88 | 1 | 259.88 | 2.66 | 0.11 |
| Group x Contrast 5 | 176.70 | 1 | 176.70 | 1.81 | 0.19 |
| Flight x Subjects | | | | | |
| Within group | 2925.90 | 30 | 97.53 | | |

Contrasts Tested:

Contrast 1 - FF vs. GP
Contrast 2 - GP 1000' vs. GP 2000'
Contrast 3 - 6000' Looking Up vs. 6000' Looking Down
Contrast 4 - 2500' vs. 9000'
Contrast 5 - 2500' and 9000' vs. 6000' Looking up and Down

$Eta^2$ (Contrast 1) = 5.36 / (5.36 + 16) = 0.251
Flight Type accounts for 29.1% of the total variance.

*Table 3. Full-Rank Model ANOVA – Size Data*

Pilots

| Obs. | Flight Type | Distance | B | Std. Err.(B) | Beta | *t* | Sig *t* |
|---|---|---|---|---|---|---|---|
| JG | GP | 1000' | 10.607143 | 1.528369 | .064268 | 6.940 | .0000 |
| JG | GP | 2000' | 24.587500 | 1.429659 | .159260 | 17.198 | .0000 |
| JG | FF | 2500' | 43.566667 | 2.334623 | .172807 | 18.661 | .0000 |
| JG | FF L.U. | 6000' | 51.035294 | 1.386973 | .389348 | 42.045 | .0000 |
| JG | FF L.D. | 6000' | 48.100000 | 1.650828 | .2669816 | 29.137 | .0000 |
| JG | FF | 9000' | 56.672222 | 1.347895 | .389348 | 42.045 | .0000 |
| RR | GP | 1000' | 27681818 | 1.724233 | .148670 | 16.055 | .0000 |
| RR | GP | 2000' | 25.00000 | 2.161441 | .107108 | 11.566 | .0000 |
| RR | FF | 2500' | 20.564706 | 1.386973 | .137302 | 14.827 | .0000 |
| RR | FF L.U. | 6000' | 15.066667 | 1.650828 | .084516 | 9.127 | .0000 |
| RR | FF L.D. | 6000' | 12.176923 | 1.586064 | .071095 | 7.677 | .0000 |
| RR | FF | 9000' | 8.2700000 | 1.808391 | .042348 | 4.573 | .0000 |
| BR | GP | 1000' | 11.092308 | 1.586064 | .064763 | 6.994 | .0000 |
| BR | GP | 2000' | 13.615385 | 1.586064 | .079494 | 8.854 | .0000 |
| BR | FF | 2500' | 20.492857 | 1.528369 | .124165 | 13.408 | .0000 |
| BR | FF L.U. | 6000' | 24.508333 | 1.650828 | .137479 | 14.846 | .0000 |
| BR | FF L.D. | 6000' | 11.806667 | 1.476545 | .074046 | 7.996 | .0000 |
| BR | FF | 9000' | 15.881250 | 1.429659 | .102867 | 11.108 | .0000 |
| JC | GP | 1000' | 6.2733333 | 1.476545 | .039344 | 4.249 | .0000 |
| JC | GP | 2000' | 28.246154 | 1.586064 | .164916 | 17.809 | .0000 |
| JC | FF | 2500' | 26.270000 | 1.808391 | .134521 | 14.527 | .0000 |
| JC | FF L.U. | 6000' | 33.500000 | 1.586064 | .195591 | 21.121 | .0000 |
| JC | FF L.D. | 6000' | 15.376923 | 1.56064 | .089779 | 6.695 | .0000 |
| JC | FF | 9000' | 46.933333 | 1.650828 | .263271 | 28.430 | .0000 |
| RbR | GP | 1000' | 6.3500000 | 1.278726 | .045985 | 4.966 | .0000 |
| RbR | GP | 2000' | 11.992857 | 1.528369 | .072664 | 7.847 | .0000 |
| RbR | FF | 2500' | 12.825000 | 1.429659 | .083071 | 8.971 | .0000 |
| RbR | FF L.U. | 6000' | 19.013043 | 1.192418 | .147655 | 15.945 | .0000 |
| RbR | FF L.D. | 6000' | 12.820000 | 2.557451 | .046420 | 5.013 | .0000 |
| RbR | FF | 9000' | 16.915385 | 1.586064 | .098761 | 10.665 | .0000 |

*Table 3. (Concluded)*

## Non-Pilots

| Obs. | Flight Type | Distance | B | Std. Err.(B) | Beta | *t* | Sig *t* |
|---|---|---|---|---|---|---|---|
| JR | GP | 1000' | 12.385714 | 1.528369 | .075044 | 8.104 | .0000 |
| JR | GP | 2000' | 13.816667 | 1.650828 | .077504 | 8.370 | .0000 |
| JR | FF | 2500' | 22.388235 | 1.386973 | .149477 | 16142 | .0000 |
| JR | FF L.U. | 6000' | 17.277778 | 1.347895 | .118701 | 12.818 | .0000 |
| JR | FF L.D. | 6000' | 15.418182 | 1.724233 | .082806 | 8.942 | .0000 |
| JR | FF | 9000' | 8.173333 | 1.476545 | .051260 | 5.535 | .0000 |
| KN | GP | 1000' | 13.163636 | 1.724233 | .070697 | 7.634 | .0000 |
| KN | GP | 2000' | 26.660000 | 1.476545 | .167200 | 18.056 | .0000 |
| KN | FF | 2500' | 27.180000 | 1.808391 | .139181 | 15.030 | .0000 |
| KN | FF L.U. | 6000' | 36.570000 | 1.808391 | .187265 | 20.222 | .0000 |
| KN | FF L.D. | 6000' | 21.490000 | 1.808391 | .110044 | 11.883 | .0000 |
| KN | FF | 9000' | 22.072727 | 1.724233 | .118545 | 12.801 | .0000 |
| PF | GP | 1000' | 1.184615 | 1.586064 | .006916 | .747 | .4554 |
| PF | GP | 2000' | 5.857143 | 1.528369 | .035488 | 3.832 | .0001 |
| PF | FF | 2500' | 10.991667 | 1.650828 | .061657 | 6.658 | .0000 |
| PF | FF L.U. | 6000' | 22.875000 | 2.021843 | .104770 | 11.314 | .0000 |
| PF | FF L.D. | 6000' | 8.269231 | 1.586064 | .048280 | 5.214 | .0000 |
| PF | FF | 9000' | 25.930769 | 1.586064 | .151397 | 16.349 | .0000 |

Table Legend [see Norusis (1997) for more details]
*B* – Regression Coefficient
*Beta* – Standardized Regression Coefficient
*t* – two-tailed 95% significance level
*Sig. t* – confidence level

*Table 4. Full-Rank Model ANOVA – Distance Data*

Pilots

| Obs. | Flight Type | Distance | B | Std. Err.(B) | Beta | *t* | Sig *t* |
|---|---|---|---|---|---|---|---|
| JG | GP | 1000' | 11.625000 | 1.406827 | .075847 | 8.263 | .0000 |
| JG | GP | 2000' | 36.094444 | 1.326370 | .249784 | 27.213 | .0000 |
| JG | FF | 2500' | 46.438462 | 1.560735 | .273110 | 29.754 | .0000 |
| JG | FF L.U. | 6000' | 49.083333 | 1.624464 | .277340 | 30.215 | .0000 |
| JG | FF L.D. | 6000' | 37.571429 | 1.503962 | .229303 | 24.982 | .0000 |
| JG | FF | 9000' | 51.093750 | 1.406827 | .333362 | 36.318 | .0000 |
| RR | GP | 1000' | 14.475000 | 1.624464 | .081789 | 8.911 | .0000 |
| RR | GP | 2000' | 12.961538 | 1.560735 | .076228 | 8.305 | .0000 |
| RR | FF | 2500' | 19.728571 | 1.503962 | .120406 | 3.118 | .0000 |
| RR | FF L.U. | 6000' | 12.810000 | 1.779512 | .066075 | 7.199 | .0000 |
| RR | FF L.D. | 6000' | 7.170000 | 1.779512 | .036983 | 4.029 | .0001 |
| RR | FF | 9000' | 11.720000 | 1.779512 | .060453 | 6.586 | .0000 |
| BR | GP | 1000' | 9.306667 | 1.452965 | .058793 | 6.405 | .0000 |
| BR | GP | 2000' | 5.461111 | 1.326370 | .037792 | 4.117 | .0000 |
| BR | FF | 2500' | 15.290000 | 1.779512 | .078867 | 8.592 | .0000 |
| BR | FF L.U. | 6000' | 29.880000 | 1.258305 | .217963 | 23.746 | .0000 |
| BR | FF L.D. | 6000' | 26.881250 | 1.406827 | .175387 | 19.108 | .0000 |
| BR | FF | 9000' | 13.871429 | 1.503962 | .084659 | 9.223 | .0000 |
| JC | GP | 1000' | -3.438889 | 1.326370 | -.023798 | -2.593 | .0097 |
| JC | GP | 2000' | 2.726667 | 1.452965 | .017225 | 1.877 | .0610 |
| JC | FF | 2500' | 48.469231 | 1.560735 | .285053 | 31.055 | .0000 |
| JC | FF L.U. | 6000' | 11.068750 | 1.406827 | .072218 | 7.868 | .0000 |
| JC | FF L.D. | 6000' | 44.855556 | 1.326370 | .310413 | 33.818 | .0000 |
| JC | FF | 9000' | 5.893333 | 1.452965 | .037230 | 4.056 | .0001 |
| RbR | GP | 1000' | 4.515789 | 1.290993 | .032107 | 3.498 | .0005 |
| RbR | GP | 2000' | 8.144444 | 1.326370 | .056362 | 6.140 | .0000 |
| RbR | FF | 2500' | 11.476923 | 1.560735 | .067497 | 7.354 | .0000 |
| RbR | FF L.U. | 6000' | 13.909524 | 1.227980 | .103970 | 11.32 | .0000 |
| RbR | FF L.D. | 6000' | 16.755556 | 1.875770 | .081991 | 8.933 | .0000 |
| RbR | FF | 9000' | 13.457143 | 1.503962 | .082131 | 8.948 | .0000 |

*Table 4. (Concluded)*

## Non-Pilots

| Obs. | Flight Type | Distance | B | Std. Err.(B) | Beta | *t* | Sig *t* |
|---|---|---|---|---|---|---|---|
| JR | GP | 1000' | 5.513333 | 1.452965 | .034830 | 3.795 | .0002 |
| JR | GP | 2000' | 6.007143 | 1.503962 | .036662 | 3.994 | .0001 |
| JR | FF | 2500' | -1.013333 | 1.452965 | -.006402 | -.697 | .4858 |
| JR | FF L.U. | 6000' | 8.621429 | 1.503962 | .052618 | 5.732 | .0000 |
| JR | FF L.D. | 6000' | -.100000 | 1.364823 | -.00067 | -.073 | .9416 |
| JR | FF | 9000' | 9.653846 | 1.560735 | .056775 | 6.185 | .0000 |
| KN | GP | 1000' | 14.923077 | 1.560735 | .087764 | 9.562 | .0000 |
| KN | GP | 2000' | 28.864706 | 1.364823 | .194124 | 21.149 | .0000 |
| KN | FF | 2500' | 27.008333 | 1.624464 | .152608 | 16.626 | .0000 |
| KN | FF L.U. | 6000' | 30.920000 | 1.452965 | .195332 | 21.281 | .0000 |
| KN | FF L.D. | 6000' | 3.473684 | 1.290993 | .024698 | 2.691 | .0073 |
| KN | FF | 9000' | 29.661538 | 1.560735 | .174443 | 19.005 | .0000 |
| PF | GP | 1000' | 9.600000 | 1.875770 | .046976 | 5.118 | .0000 |
| PF | GP | 2000' | 12.092857 | 1.503962 | .073804 | 8.041 | .0000 |
| PF | FF | 2500' | 18.513333 | 1.452965 | .116955 | 12.742 | .0000 |
| PF | FF L.U. | 6000' | 12.305882 | 1.364823 | .082761 | 9.016 | .0000 |
| PF | FF L.D. | 6000' | 5.850000 | 1.779512 | .030175 | 3.287 | .0011 |
| PF | FF | 9000' | 27.894118 | 1.364823 | .187597 | 20.438 | .0000 |

Table Legend [see Norusis (1997) or more details]

*B* – Regression Coefficient
*Beta* – Standardized Regression Coefficient
*t* – Two-tailed 95% Significance Level
*Sig. t* – Confidence Level

*Table 5. Contrast Tests of Interobserver Differences – Size Data*

| | SS | df | MS | F | p |
|---|---|---|---|---|---|
| RR vs. JG | 15057.58 | 1 | 15057.58 | 460.44 | < 0.001 |
| RR vs. BR | 130.35 | 1 | 130.35 | 3.99 | < 0.046 |
| RR vs. RbR | 786.97 | 1 | 786.97 | 24.06 | < 0.001 |
| RR vs. JC | 2214.20 | 1 | 2214.20 | 67.71 | < 0.001 |
| JR vs. KN | 3411.16 | 1 | 3411.16 | 104.31 | < 0.001 |
| JR vs. PF | 219.76 | 1 | 219.76 | 6.72 | 0.01 |
| JG vs. BR | 20100.97 | 1 | 20100.97 | 614.66 | < 0.001 |
| JG vs. RbR | 23854.49 | 1 | 23854.49 | 729.43 | < 0.001 |
| JG vs. JC | 6209.09 | 1 | 6209.09 | 189.86 | < 0.001 |
| KN vs. PF | 4898.91 | 1 | 4898.91 | 149.80 | < 0.001 |
| BR vs. RbR | 324.35 | 1 | 324.35 | 9.92 | < 0.002 |
| BR vs. JC | 3815.81 | 1 | 3815.81 | 116.68 | < 0.001 |
| RbR vs. JC | 5969.30 | 1 | 5969.30 | 182.53 | < 0.001 |
| ERROR | 19033.02 | 582 | 32.70 | | |

*Table 6. Contrast Tests of Interobserver Differences – Distance Data*

| | SS | df | MS | F | p |
|---|---|---|---|---|---|
| RR vs. JG | 24813.02 | 1 | 24813.02 | 783.57 | < 0.001 |
| RR vs. BR | 507.92 | 1 | 507.92 | 16.04 | < 0.001 |
| RR vs. RbR | 118.78 | 1 | 118.78 | 3.75 | .053 |
| RR vs. JC | 1030.06 | 1 | 1030.06 | 32.53 | < 0.001 |
| JR vs. KN | 13625.87 | 1 | 13625.87 | 430.29 | < 0.001 |
| JR vs. PF | 3771.93 | 1 | 3771.93 | 119.11 | < 0.001 |
| JG vs. BR | 21038.38 | 1 | 21038.38 | 664.37 | < 0.001 |
| JG vs. RbR | 32362.59 | 1 | 32362.59 | 1021.98 | < 0.001 |
| JG vs. JC | 18797.78 | 1 | 18797.78 | 593.61 | < 0.001 |
| KN vs. PF | 2676.96 | 1 | 2676.96 | 84.54 | < 0.001 |
| BR vs. RbR | 1280.44 | 1 | 1280.44 | 40.43 | < 0.001 |
| BR vs. JC | 99.91 | 1 | 99.91 | 3.15 | .076 |
| RbR vs. JC | 2135.99 | 1 | 2135.99 | 67.45 | < 0.001 |
| ERROR TERM | 20614.97 | 651 | 31.67 | | |